

# Branching ratio measurements of the 7.12-MeV state in $^{16}\text{O}$

C. Matei<sup>a</sup> and C. R. Brune<sup>a</sup>

<sup>a</sup>Edwards Accelerator Laboratory, Department of Physics and Astronomy,  
Ohio University, Athens OH 45701, USA

Knowledge of the  $\gamma$ -ray branching ratios of the 7.12-MeV state of  $^{16}\text{O}$  is important for the extrapolation of the  $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$  cross section to astrophysical energies. Ground state transitions provide most of the  $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$  total cross section while cascade transitions have contributions of the order of 10-20%. Determining the  $7.12 \rightarrow 6.92$ -MeV branching ratio will also result in a better extrapolation of the cascade and  $E2$  ground state cross section to low energies. We report here on measurements on the branching ratio of the  $7.12 \rightarrow 6.92$ -MeV transition in  $^{16}\text{O}$ .

## 1. INTRODUCTION

A typical star spends 90% of its lifetime burning hydrogen on the Main Sequence. When hydrogen is exhausted in the center, the remaining helium core contracts transforming gravitational potential energy into thermal energy. As the temperature increases helium burning starts. The first step of this process is the triple- $\alpha$  capture to form  $^{12}\text{C}$ , followed by the  $^{12}\text{C}$  radiative capture of  $\alpha$  particles to form  $^{16}\text{O}$  [1]. In the helium-burning phase of stellar evolution the triple- $\alpha$  process and  $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$  are the most important reactions. Their relative reaction rates determine the  $^{12}\text{C}/^{16}\text{O}$  ratio at the end of helium burning and beyond. The triple- $\alpha$  reaction rate is well known for stellar evolution calculations. However the rate of  $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$  is poorly determined as the cross section was measured experimentally down to energies around 1 MeV and needs to be extrapolated to helium-burning energies around 300 keV. The  $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$  cross section is composed of 3 major parts:  $E1$ ,  $E2$  ground state transitions and cascade transitions. Ground state transitions provide most of the total cross section while cascade transitions have contributions of the order of 10-20%. Determining the  $7.12 \rightarrow 6.92$ -MeV branching ratio will result in a better extrapolation of the cascade and  $E2$  ground state cross sections to lower energies [2].

## 2. EXPERIMENTAL DETAIL

The 7.12-MeV excited state in  $^{16}\text{O}$  is formed via the  $^{19}\text{F}(p, \alpha)^{16}\text{O}^*$  reaction; a level diagram is shown in Fig. 1. A  $100\text{-}\mu\text{g}/\text{cm}^2$ -thick  $\text{CaF}_2$  layer evaporated onto a 1-mm-thick carbon backing was bombarded by protons produced at the 4.5-MV Tandem Van de Graaf Accelerator at Ohio University.

An angular distribution study for the 7.12-MeV  $\gamma$ -ray at 4 different proton energies was performed. These measurements offered a better understanding of the  $\gamma$ -ray angular

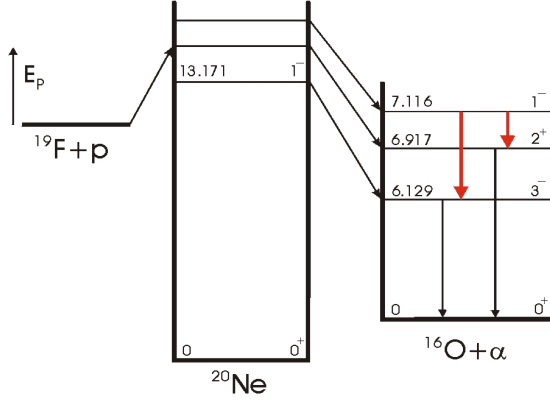


Figure 1. Level schemes of  $^{16}\text{O}$  and  $^{20}\text{Ne}$  to illustrate how the  $^{19}\text{F}(p,\alpha\gamma)^{16}\text{O}$  reaction proceeds.

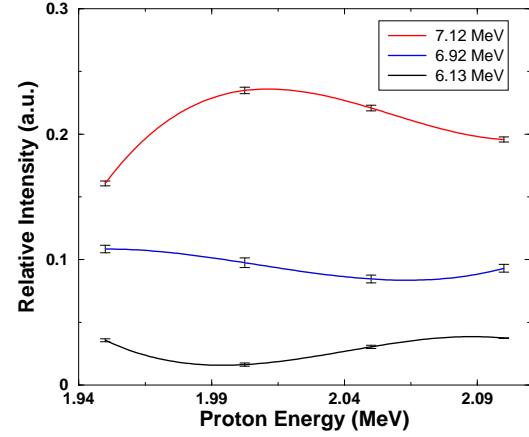


Figure 2. Relative intensities of the three transitions at proton energies between 1.95 MeV and 2.1 MeV

distribution for the strong transitions and information on the dependence of the relative intensity of the three  $\gamma$ -ray components with proton energy. In Fig. 2 the relative intensities of the strong transitions in the direction of the beam are shown. For the branching-ratio measurements the proton beam energy was chosen to be  $E_p = 2.0025$  MeV in order to maximize the relative population of the 7.12-MeV state [3].

The coincidence setup uses a two-detector configuration. For the detection of the  $6.92 \rightarrow 0$ -MeV transition, a 22.9-cm  $\times$  22.9-cm NaI(Tl) split annulus consisting of two optically-isolated sections is used. The large volume of the crystal offers a 30% efficiency in detecting the 6-7 MeV  $\gamma$ -rays. The inside cylindrical hole in the crystal is able to accommodate an extended target holder as sketched in Fig. 3.

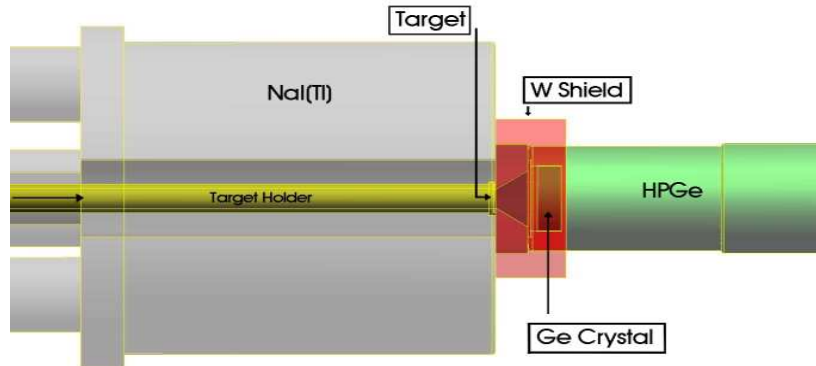


Figure 3. Schematic view of the experimental setup. The beam enters from left.

For the  $7.12 \rightarrow 6.92$ -MeV transition a HPGe detector is used. This detector has a planar geometry to lower the noise and achieve better time resolution for low-energy gamma rays. The efficiency of different detector geometries and thicknesses was simulated using the GEANT3 simulation package. The simulation looked for the optimum Ge thickness to maximize the photopeak efficiency at 200 keV while minimizing the sensitivity to 7-MeV  $\gamma$ -rays. A planar crystal of 1.5-cm thickness and 2000-mm<sup>2</sup> area was chosen.

To further lower the background in the 0.2-MeV region of interest a tungsten shield was utilized to minimize the scattering of  $\gamma$ -rays between detectors. The design of the shield was also guided by the GEANT3 simulation package.

### 3. EXPERIMENTAL RESULTS

Data on  $\gamma$ - $\gamma$  coincidences was taken for 4 days, in 24 hour shifts, with beam currents ranging from 10 to 20 nA. A standard coincidence setup fed the signal from the detectors and the Time-to-Amplitude Converter (TAC) into a 4096 channels data acquisition system. The time resolution of the system (for energy signals of interest) was 5 ns.

The spectrum shown in Fig. 4 was obtained by the HPGe detector using gate settings on the TAC coincidence peak and the 6-7 MeV region in the NaI(Tl) detector.

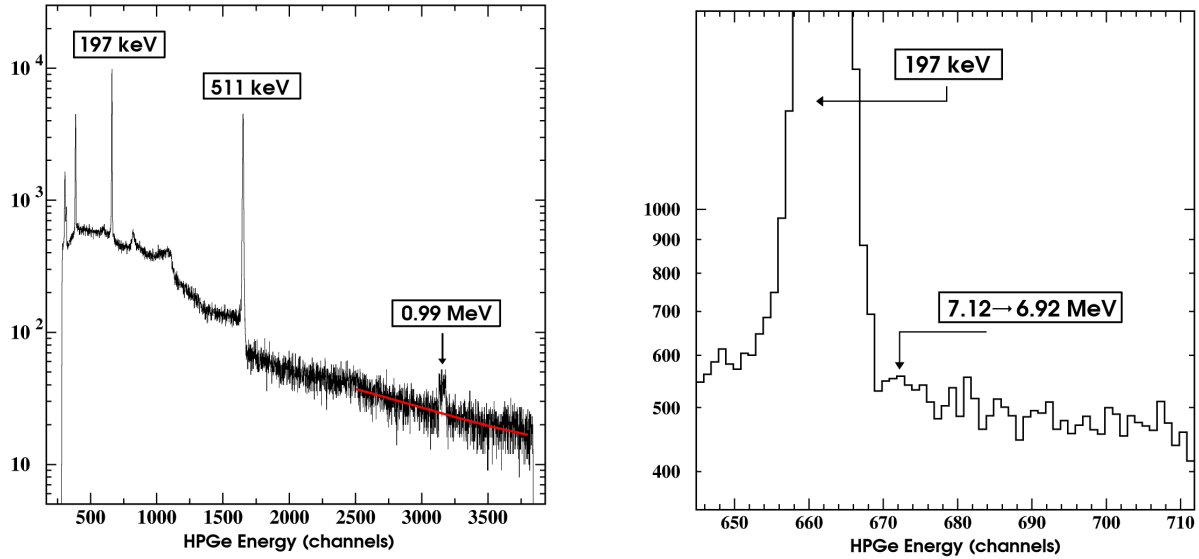


Figure 4. HPGe spectrum in coincidence with the 6-7 MeV region in NaI(Tl). Left figure: The 0.99 MeV peak from the  $7.12 \rightarrow 6.13$ -MeV transition is indicated. Right figure: Expanded 200-keV region with the 197-keV peak from the  $^{19}\text{F}(p,p')$  reaction and the position of a possible  $7.12 \rightarrow 6.92$ -MeV transition.

For the  $7.12 \rightarrow 6.13$ -MeV transition the peak is clearly visible between channels 3000 and 3250 in Fig. 4. The region surrounding the peak was fitted to subtract the background and obtain the number of counts in the  $7.12 \rightarrow 6.13$ -MeV transition peak. Calibrated

sources and GEANT3 simulations were used to find the efficiencies of the detectors. The result obtained for this branching ratio is  $(8.4 \pm 0.4) \times 10^{-4}$ , in good agreement with a previous measurement by Wilkinson et al. [4].

The coincident HPGe spectrum near 200 keV is dominated by the 197.1-keV line which results from random-coincidence  $^{19}\text{F}(\text{p},\text{p}')$  events detected in the HPGe. No peak is evident at 199.8 keV corresponding to the  $7.12 \rightarrow 6.92$ -MeV transition. It should be noted that the HPGe detector resolution is 1.3 keV at 200 keV, so energy range of interest is well resolved from the 197.1-keV line. From the spectrum shown in Fig. 4 we have obtained the following upper limit with a  $2\text{-}\sigma$  confidence level:

$$\frac{\Gamma(7.12 \rightarrow 6.92)}{\Gamma(7.12 \rightarrow 0)} \leq 1.2 \times 10^{-5}. \quad (1)$$

Note that if the  $7.12 \rightarrow 6.92$ -MeV transition were to have the same Weisskopf strength as the  $7.12 \rightarrow 0$ -MeV transition this branching ratio would be  $(0.2/7.12)^3 = 2 \times 10^{-5}$ .

The results are preliminary and further analysis of the data may reveal more information. Histogram manipulation and improved GEANT3 simulations will be performed to further understand the limitations of the present setup and perhaps discover improvements to the experimental approach.

#### 4. ACKNOWLEDGMENTS

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